Tanta University | Department: Mechanical power Engineering | Faculty of Engineering

Total Marks: 90 Marks

Course Title: Heat transfer (1)	Course Code: MEP2206	Year: 2nd
Date: June 12nd 2011 (Second term)	Allowed time: 3 hrs	No. of Pages: (2)

Problem number (1) (18 Marks)

a) Heat is uniformly generated inside a hollow circular cylinder by the rate of qv (W/m³). The cylinder has an inner radius R1, outer radius R2, thermal conductivity k and enough long length such that all of the generated heat is considered to diffuse in the radial direction. The outer surface of the cylinder is perfectly insulated while the inner surface is always under a uniform temperature Tw1 due to presence of fluid flow inside the cylinder. Starting from the general equation of heat conduction in cylindrical coordinates:

$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{1}{r^2}\frac{\partial^2 T}{\partial \Phi^2} + \frac{\partial^2 T}{\partial z^2} + \frac{q_v}{k} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau}$$

Deduce an expression for the temperature distribution inside the wall of the cylinder and show that the maximum temperature inside the wall is expressed as the following:

$$T_{max} = T_{w1} + \frac{q_v R_1^2}{4k}\left[1 - \left(\frac{R_2}{R_1}\right)^2\right] + \frac{q_v R_2^2}{2k} \mathrm{Ln}\left(\frac{R_2}{R_1}\right)$$

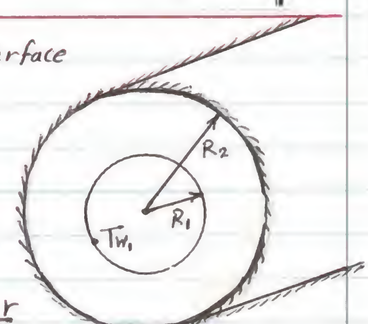
(9 Marks)

Given: Hollow cylinder insulated at outer surface

From general equation and assumption that

1- one dimensional H.T, 2- steady state H.T,

3- with internal heat generation. we get



$$\frac{\partial^2 T}{\partial r^2} + \frac{1}{r}\frac{\partial T}{\partial r} + \frac{q_v}{K} = 0 \quad ; \text{Multiplying by "r"}$$

$$r.\frac{\partial^2 T}{\partial r^2} + \frac{\partial T}{\partial r} = -\frac{q_v . r}{K} \iff \frac{\partial}{\partial r}\left(r.\frac{\partial T}{\partial r}\right) = \frac{-q_v . r}{K}$$

By integration twice $\Rightarrow r.\frac{\partial T}{\partial r} = -\frac{q_v . r^2}{2K} + C_1 \Rightarrow \frac{\partial T}{\partial r} = \frac{-q_v . r}{2K} + \frac{C_1}{r} \to$ (I)

$$T = -\frac{q_v . r^2}{4K} + C_1 . \ln r + C_2 \longrightarrow \text{(II)}$$

To find C_1, C_2 use the boundary conditi

B.Conditions: At $r = R_1 \to T = T_{w1}$ and At $r = R_2 \to T = T_{max}$, $\frac{dT}{dr} = 0$

where at $r = R_2 \Rightarrow \frac{dT}{dr} = 0 \Rightarrow 0 = \frac{-q_v . R_2}{2K} + \frac{C_1}{R_2} \Rightarrow \boxed{C_1 = \frac{q_v . R_2^2}{2K}}$

Where at $r = R_1 \Rightarrow T = T_{w_1} \Rightarrow T_{w_1} = -\frac{q_v \cdot R_1^2}{4K} + \frac{q_v \cdot R_2^2}{2K} \cdot \ln R_1 + C_2$

$$\therefore \boxed{C_2 = T_{w_1} + \frac{q_v \cdot R_1^2}{4K} - \frac{q_v \cdot R_2^2}{2K} \ln R_1}$$

substituting in equation (II) by values of C_1 and C_2

$$T = -\frac{q_v \cdot r^2}{4K} + \frac{q_v \cdot R_2^2}{2K} \ln r + T_{w_1} + \frac{q_v \cdot R_1^2}{4K} - \frac{q_v \cdot R_2^2}{2K} \ln R_1$$

$$\boxed{T = T_{w_1} + \frac{q_v \cdot R_2^2}{2K} \cdot \ln\left(\frac{r}{R_1}\right) - \frac{q_v}{4K}\left(r^2 - R_1^2\right)}$$

→ An expression for the temperature distribustion inside the wall of the cylinder.

where at $r = R_2 \Rightarrow T = T_{max}$ and $Q)_{r=R_2} = 0$

$$T_{max} = T_{w_1} + \frac{q_v \cdot R_2^2}{2K} \cdot \ln\left(\frac{R_2}{R_1}\right) - \frac{q_v}{4K}\left(R_2^2 - R_1^2\right)$$

$$\boxed{T_{max} = T_{w_1} + \frac{q_v \cdot R_1^2}{4K}\left[1 - \left(\frac{R_2}{R_1}\right)^2\right] + \frac{q_v \cdot R_2^2}{2K} \cdot \ln\left(\frac{R_2}{R_1}\right)}$$

→ Expression for the maximum temperature inside the wall of hollow cylinder insulated at outer surface.

b) The suction line of a refrigerator carries a refrigerant at -20 ºC and surrounded by air at 20 ºC, the pipe line is made of a steel tube of 50 mm inner diameter, 5 mm wall thickness and thermal conductivity of 58 W/m.K. If the inside and outside convective heat transfer coefficient is 2300 and 6 W/m^2.k respectively and kins = 0.042 W/m.K, calculate:

a) The thickness of insulation which prevent water vapor to be condensed at the outer side, considering that the dew point of air is 15 ºC.

b) The rate of heat transfer from air to the pipe per unit length. (9 Marks)

Given: pipe $d_i = 50\,mm$, wall thickness $= 5\,mm$

$T_\infty = 20°C$, $T_{Ref} = -20°C$

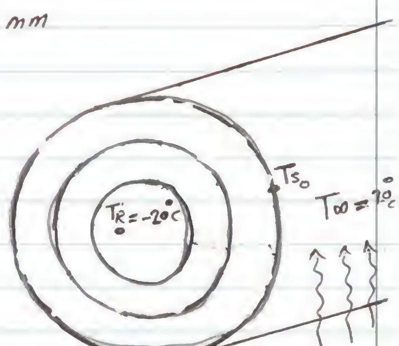
$h_i = 2300\ W/m^2.K$, $h_o = 6\ W/m^2.K$

$K_s = 58\ W/m.K$, $K_{ins} = 0.042\ W/m.K$

Req:- (a) Insulation thickness $T_{dp} = 15°C$

To prevent water vapor from condensation

(b) $q' = \frac{Q}{L} = ?$



Soln

Where

$$Q = \frac{\Delta T}{\Sigma R_{th}}$$

T_{Ref} — R_{conv_i} — $R_{cond_{steel}}$ — $R_{cond_{insul}}$ — T_{s_o} — R_{conv_o} — T_∞

$$\frac{1}{h_i\, 2\pi r_1 \cdot L} \qquad \frac{\ln r_2/r_1}{2\pi K_s \cdot L} \qquad \frac{\ln r_3/r_2}{2\pi K_{ins} \cdot L} \qquad \frac{1}{h_o \cdot 2\pi r_3 \cdot L}$$

For steady state heat transfer

$$q' = \frac{Q}{L} = \frac{T_\infty - T_{so}}{\frac{1}{h_o \cdot 2\pi r_3}} = \frac{T_{so} - T_{Ref}}{\frac{1}{h_i\, 2\pi r_1} + \frac{\ln r_2/r_1}{2\pi K_s} + \frac{\ln r_3/r_2}{2\pi K_{ins}}} \rightarrow \mathrm{I}$$

هناك طريقتان للحل هما ① يتم حساب سمك مادة العازل على اعتبار $T_{so}=15^\circ C$ ولكن عند هذه الدرجة حيث تتكثف بخار الماء على السطح الخارجي للماسورة لذلك بعد حساب السمك يكون السمك المطلوب فعليا أكبر منه قليلاً لمنع حدوث التكثف لبخار الماء.

② يتم فرض درجة حرارة السطح $T_{so} = 17^\circ C$ وحساب السمك ويكون هو المطلوب.

Let $T_{so} = 15^\circ C$, $r_1 = 0.025\ m$, $r_2 = 0.03\ m$, $T_\infty = 20^\circ C$

$T_{Ref} = -20^\circ C$, $h_i = 2300\ W/m^2 K$, $h_o = 6\ W/m^2 K$, $K_s = 58\ W/m.K$

$K_{ins} = 0.042\ W/m.K$

$$\frac{(20-15)}{\frac{1}{6 * 2\pi * r_3}} = \frac{15 - (-20)}{\frac{1}{2300 * 2\pi * 0.025} + \frac{\ln(30/25)}{2\pi * 58} + \frac{\ln(r_3/0.03)}{2\pi * 0.042}}$$

$$188.495 * r_3 = \frac{35}{2.768 * 10^{-3} + 5 * 10^{-4} + \frac{\ln(r_3/0.03)}{0.2639}}$$

By trial and error

Let $r_3 = 35\ mm \Rightarrow L.H.S = 6.597$ and $R.H.S = 59.585$

Let $r_3 = 45\ mm \Rightarrow L.H.S = 8.48$ and $R.H.S = 22.732$

Let $r_3 = 60\ mm \Rightarrow L.H.S = 11.3097$ and $R.H.S = 13.3089$

Let $r_3 = 63\ mm \Rightarrow L.H.S = 11.875$ and $R.H.S = 12.435$

Let $r_3 = 65\ mm \Rightarrow L.H.S = 12.252$ and $R.H.S = 11.933$

$\Rightarrow 63 < r_3 < 65 \Rightarrow$ To prevent water vapor from condensation on outer surface of the pipe take $r_3 = 66\ mm$

so that The thickness of insulation $= r_3 - r_2 = 36\ mm$

and $$q' = \frac{Q}{L} = \frac{T_\infty - T_{so}}{\frac{1}{h_o \cdot 2\pi r_3}} = \frac{20-15}{\frac{1}{6 * 2\pi * 0.066}} = 12.441\ \frac{W}{m}$$

Problem number (2) **(14 Marks)**

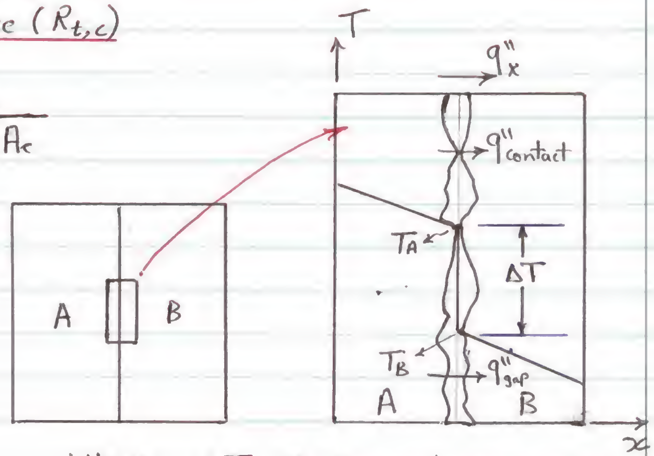
a) What are the thermal contact resistance, critical radius of insulation, superinsulation, and fin effectiveness? (6 Marks)

b) An aluminum rod of 2.5 cm diameter and 15 cm long is protrudes from a wall maintained at 260 ºC. The rod is exposed to an environment at 16 ºC. The convective heat transfer coefficient is 15 W/m^2.ºC. If the thermal conductivity of aluminum is 200 W/m.K. Calculate the heat loss by the rod. (8 Marks)

ⓐ - Thermal contact resistance ($R_{t,c}$)

$$R''_{t,c} = \frac{T_A - T_B}{q''_x} = \frac{1}{h_c \cdot A_c}$$

خلال جدار مركب و عند سطح
الإتصال بين مادتين إذا كان
بين السطحين عند السطح الفاصل
فراغات تنشأ مقاومة إضافية
بخلاف مقاومة كل مادة على حده
تسمى بمقاومة الإتصال وتسبب
حدوث إنخفاض في درجة الحرارة
فجأة عند سطح الإتصال.

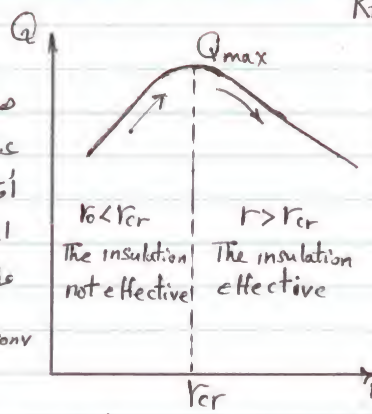


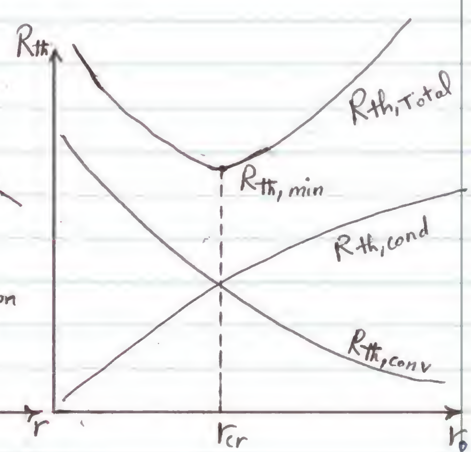
Where: ΔT : The temperature drop due to thermal contact resistance

- Critical radius of insulation (r_{cr})

نصف القطر الحرج للعازل
هو نصف القطر الذي يكون
عنده معدل إنتقال الحرارة
أقصى ما يمكن Q_{max} أو يكون
المقاومة الحرارية الكلية أقل
ما يمكن

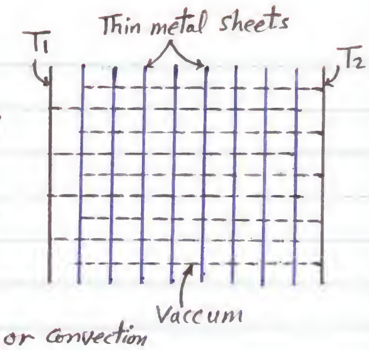
$$R_{th,T} = R_{th_{cond}} + R_{th_{conv}}$$





$$r_{cr})_{cylinder} = \frac{K_{insul}}{h_o} \quad \text{and} \quad r_{cr})_{sphere} = \frac{2\,K_{insul}}{h_o}$$

- Superinsulation: Are built by closely packing Layers of highly reflective Thin metal sheets and evacuating the space between them.



أي يتم عمل عزل فائق، وذلك بوضع ألواح رقيقة من المعدن ذو معامل
الانعكاسية العالية (Radiation shield) وتكون قريبة جدا (25 sheet/cm)
، وذلك لتقليل الإشعاع بقدر الإمكان كذلك يتم عمل تفريغ بين الألواح
، وذلك لضمان تقليل كلا من الـ conduction، والـ Convection لأقل ما يمكن

⇒ Evacuating the space between two surfaces completely eliminates heat transfer by conduction or convection but leaves the door wide open for radiation.

- Fin effectivness:

$$\epsilon_{fin} = \frac{Q_{fin}}{Q_{with}} = \frac{\text{Actual heat transfer by fin}}{\text{Heat transfer without fin}}$$

For long and thin (insulated tip) fin

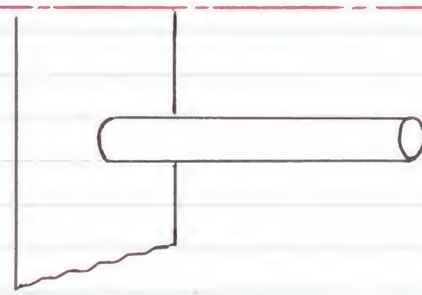
$$\epsilon_{fin} = \frac{\sqrt{hPKA_c} * \theta_o * \tanh mL}{h * A_c * \theta_o} = \frac{\text{كمية الحرارة الفعلية المنتقلة من سطح الزعنفة حسب القانون}}{\text{كمية الحرارة المنتقلة من الأساس التي تم تركيب الزعنفة عليه}}$$

and also The overall effectiveness of fin

$$\epsilon_{fin,\,overall} = \frac{\text{no of fins} * Q_{fin} + Q_{\text{remain surface between fins}}}{Q_{\text{without fin}}}$$

كمية الحرارة المنتقلة من السطح كله بدون زعانف

ⓑ Data: circular fin ≡ pin fin



$D = 2.5\ cm$, $L = 15\ cm$

$T_o = 260^\circ C$, $T_\infty = 16^\circ C$

$h = 15\ W/m^2.^\circ C$, $K = 200\ W/m.K$

Req:- Q_{fin} ≡ heat loss by fin

soln:-

We have short fin with convective end

$$Q_{fin} = \sqrt{hPKA_c} * \theta_o * \frac{\sinh mL + \frac{h}{m.K}\cosh mL}{\cosh mL + \frac{h}{m.K}\sinh mL}$$

where: $A_c = \frac{\pi}{4} \cdot D^2 = \frac{\pi}{4}(0.025)^2 = 4.91 * 10^{-4}\ m^2$

$P = \pi D = \pi * 0.025 = 0.07854\ m$

also $\Rightarrow m = \sqrt{\frac{h \cdot P}{K \cdot A_c}} = \sqrt{\frac{15 * 0.07854}{200 * 4.91 * 10^{-4}}} = 3.4636$

$mL = 3.4636 * 0.15 = 0.51955$

$\theta_o = T_o - T_\infty = 260 - 16 = 244$

also $\frac{h}{m \cdot K} = \frac{15}{3.4636 * 200} = 0.02165$

$\cosh mL = 1.1381$ and $\sinh mL = 0.54332$

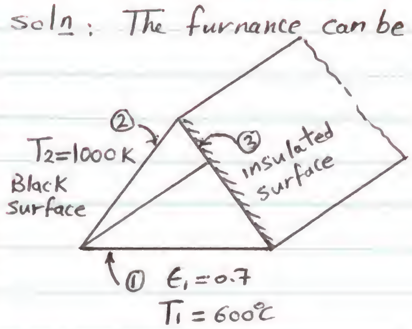
$$Q_{loss} = \sqrt{15 * 0.07854 * 200 * 4.91 * 10^{-4}} * 244 * \frac{0.54332 + 0.02165 * 1.1381}{1.1381 + 0.02165 * 0.54332}$$

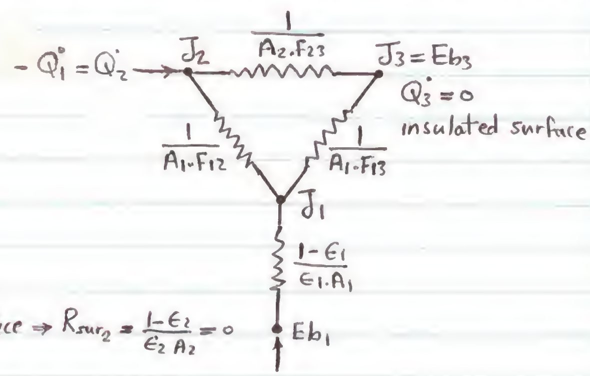
$\therefore\ Q_{loss} = 40.9875 \simeq 41\ W$

Problem number (3) **(18 Marks)**

a) A furnace is shaped like a long equilateral triangular duct which its each side width is 1m. The base surface has an emissivity of 0.7 and is maintained at a uniform temperature of 600 K. The heated left side surface is closely approximated as a black surface at 1000 K. The right side surface is well insulated. Determine the rate at which energy must be supplied to the heated side externally per unit length of the duct in order to maintain these operating conditions. (12 Marks)

soln: The furnance can be considered to be a three-surface enclosure





Notes: ① surface ② is black surface $\Rightarrow R_{sur_2} = \frac{1 - \epsilon_2}{\epsilon_2 A_2} = 0$
and $J_2 = E_{b_2} = \sigma \cdot T_2^4$

② surface ③ is insulated (Adiabatic) $\equiv$ Reradiating surface $\Rightarrow R_{sur_3} = 0$
$Q_3^\circ = 0$ and $J_3 = \sigma T_3^4 = E_{b_3}$

Since the duct is very long and thus the end effects are negligible from summation and symmetry rules we obtain

$F_{11} + F_{12} + F_{13} = 1$ also $F_{12} = F_{13}$
$\quad \downarrow 0$

$\therefore \; F_{12} = F_{13} = 0.5$ and $F_{23} = 0.5$

$\Rightarrow$ Because surface ③ is Reradiating surface $\Rightarrow \dot{Q}_3 = 0$

$\therefore \; \dot{Q}_1 = -\dot{Q}_2$

لأنه كل حرارة الخارجة من السطح ② بالإشعاع يجب أن تمتص عن طريق السطح ①

where

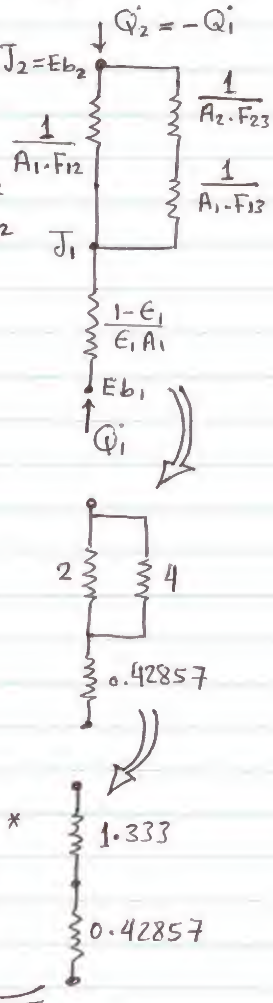
$$\dot{Q}_1 = \frac{E_{b1} - E_{b2}}{\sum R_{th}}$$

$\Rightarrow A_1 = A_2 = A_3 = 1 * 1 = 1\,m^2$

$F_{12} = F_{13} = F_{23} = 0.5$

$E_{b1} = \sigma T_1^4 = 5.67 * 10^{-8} * (600)^4 = 7348\ W/m^2$

$E_{b2} = \sigma T_2^4 = 5.67 * 10^{-8} * (1000)^4 = 56700\ W/m^2$



$$\Rightarrow \frac{1}{A_1 \cdot F_{12}} = \frac{1}{A_1 \cdot F_{13}} = \frac{1}{A_2 \cdot F_{23}} = \frac{1}{1 * 0.5} = 2$$

and

$$\frac{1-\epsilon_1}{\epsilon_1 \cdot A_1} = \frac{1-0.7}{0.7 * 1} = \frac{0.3}{0.7} = 0.42857$$

المقاومة المكافئة للمقاومتين (4&2) توازي

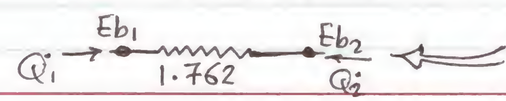
$$R_{eqn} = \frac{2 * 4}{2 + 4} = \frac{8}{6} = 1.333$$

$\Rightarrow \sum R_{th} = 1.333 + 0.42857 = 1.762$

$$\dot{Q}_1 = \frac{E_{b1} - E_{b2}}{\sum R_{th}} = \frac{7348 - 56700}{1.762}$$

$\dot{Q}_1 = 28010.6$ Watt

* معنى ذلك يجب إمداد السطح (Heated surface) الساخن بمعدل من الطاقة مقداره 28010.6 W للحفاظ على ظروف التشغيل المستقرة لهذا الغرض.



(a) - The lumped heat capacity analysis is one which assumes that the internal resistance of the body is negligible in comparison with the external resistance. In general, the smaller the physical size of the body, the more realistic the assumption of a uniform temperature throughout.

→ The physical assumptions necessary for a lumped-capacity unsteady state analysis to apply are:
"small bodies with high thermal conductivity are good candidates for lumped system analysis, especially when they are in a medium that is poor conductor of heat (such as air or another gas) and motionless".

When the body with
1. small volume and large surface area
2. high thermal conductivity
3. small convection heat transfer coefficient

when the Boit number

$$Bi = \frac{h * (\frac{V}{A_s})}{K} < 0.1$$

and

$$T = fn(\tau)$$

$$\frac{T(\tau) - T_\infty}{T_i - T_\infty} = e^{-\frac{hA_s}{\rho V C} \cdot \tau}$$

(b) * Biot number $(Bi) = \dfrac{\text{Conduction resistance within the body}}{\text{Convection resistance at the surface of the body}} = \dfrac{L/K}{(\frac{1}{h})}$

$$Bi = \frac{h}{(K/L_c)} = \frac{\text{Convection at the surface of the body}}{\text{Conduction within the body}}$$

* Fourier number $= F_o = \dfrac{\alpha \tau}{L_c^2}$ It is adimensionless time

$$= \frac{K}{\rho \cdot C} \cdot \frac{\tau}{L_c^2} = \frac{\text{Heat transfer by conduction}}{\text{stored heat}}$$

(c) Data: Cube of aluminum ≡ Rectangular parallelepiped

$2L_1 = 2L_2 = 2L_3 = 10\ cm$

$T_i = 300°C$, $T_\infty = 100°C$, $h = 900\ W/m^2.°C$

Req:- (a) Temperature at center of one face after 1 min ⇒ $T(x,y,z,\tau) = ?$ $= T(x,0,0,\tau)$

(b) heat loss from the cube.

soln Where $$\frac{T(x,y,z,\tau) - T_\infty}{T_i - T_\infty} = \underbrace{\frac{T(x,\tau) - T_\infty}{T_i - T_\infty}\Big)}_{P.W_1} * \underbrace{\frac{T(0,\tau) - T_\infty}{T_i - T_\infty}\Big)}_{P.W_2} * \underbrace{\frac{T(0,\tau) - T_\infty}{T_i - T_\infty}\Big)}_{P.W_3}$$

For plane wall (1) $L = 5\ cm$

also $x = 5\ cm$ (on one face) ⇒ $\frac{x}{L} = 1$

For aluminum from table (take pure aluminum)

$\rho = 2702\ Kg/m^3$, $C_p = 903\ J/kg.K$, $K = 237\ W/m.K$ and

$\alpha = 97.1 * 10^{-6}\ m^2/s$

so $\frac{K}{h.L} = \frac{237}{900 * 0.05} = 5.267$

$\frac{\alpha.\tau}{L^2} = \frac{97.1 * 10^{-6} * 60}{(0.05)^2} = 2.3304$

From charts of plane wall

chart (1) $\frac{\theta_o}{\theta_i} = 0.7$

chart (2) $\frac{\theta}{\theta_o} = 0.91$

$$\Rightarrow \left(\frac{\theta}{\theta_i}\right)_{plane.w(1)} = \frac{\theta}{\theta_o} * \frac{\theta_o}{\theta_i} = 0.91 * 0.7 = 0.637 = \frac{T(x,\tau) - T_\infty}{T_i - T_\infty}\Big)_{P.W(1)}$$

For plane wall (2)
For plane wall (3) $\left[\frac{K}{h.L} = 5.267 \quad \frac{\alpha.\tau}{L^2} = 2.3304\right]$ chart (1) $\frac{\theta_o}{\theta_i} = 0.7$

$$\left(\frac{\theta}{\theta_i}\right)_{plane.w(2)\ or\ (3)} = \left(\frac{\theta_o}{\theta_i}\right) = \frac{T(0,\tau) - T_\infty}{T_i - T_\infty} = 0.7$$

so that $$\frac{T(x,0,0,\tau) - T_\infty}{T_i - T_\infty} = 0.637 * 0.7 * 0.7 = 0.31213$$

$$\Rightarrow T(x,y,z,\tau) = T(x,0,0,\tau) = 0.31213 * (T_i - T_\infty) + T_\infty$$

$$T(x,0,0,\tau) = 0.31213 * (300 - 100) + 100 = 162.426\ °C$$

→ Temperature at center of one face after 1 min

To find the heat loss from the cube

$$\left(\frac{Q}{Q_o}\right)_{3D} = \left(\frac{Q}{Q_o}\right)_1 + \left(\frac{Q}{Q_o}\right)_2 \left[1 - \left(\frac{Q}{Q_o}\right)_1\right] + \left(\frac{Q}{Q_o}\right)_3 \left[1 - \left(\frac{Q}{Q_o}\right)_1\right]\left[1 - \left(\frac{Q}{Q_o}\right)_2\right] \quad \text{II}$$

From chart 3 for plane wall at:

$$\left.\begin{aligned} Fo \cdot Bi^2 &= \frac{h^2 . \alpha . \tau}{K^2} = \frac{900^2 * 97.1*10^{-6} * 60}{(237)^2} = 0.084 \\ Bi &= \frac{h L}{K} = \frac{900 * 0.05}{237} = 0.18987 \end{aligned}\right\} \frac{Q}{Q_o} = 0.3$$

Note $\frac{Q}{Q_o}$ is the same value for all plane wall 1, 2 and 3

substituting in eqn II We obtain

$$\left.\frac{Q}{Q_o}\right)_{Total} = 0.3 + 0.3(1-0.3) + 0.3(1-0.3)(1-0.3)$$

$$= 0.3 + 0.3 * 0.7 + 0.3 * 0.7 * 0.7 = 0.657$$

Where

$$Q_o = \rho * C * V * (T_i - T_\infty)$$

$$= 2702 * 903 * (0.1 * 0.1 * 0.1) * (300 - 100)$$

$$= 487981.2 \text{ W}$$

So that

$$Q = Q_o * \left.\frac{Q}{Q_o}\right)_{Total} = 487981.2 * 0.657$$

$\Rightarrow$ The heat loss from the cube Q

$$Q = 320603.65 \text{ W} = 320.6 \text{ KW}$$

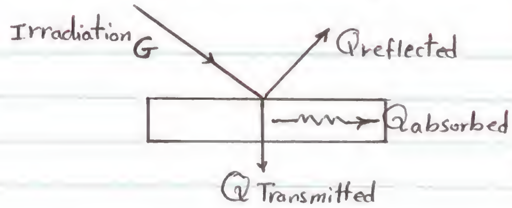
Problem number (5) (20 Marks)

a) Define irradiation and radiosity. (4 Marks)

b) What is a black body? (4 Marks)

c) A mercury-in-class thermometer having $\epsilon = 0.9$ hangs in a metal building and indicates a temperature of 20 °C. The walls of the building are poorly 5 °C. The value of h for the thermometer may be taken as 8.3 W/m^2. °C. Calculate the true air temperature. (12 Marks)

ⓐ **Irradiation:** The rate of radiation incident on a surface per unit area. where

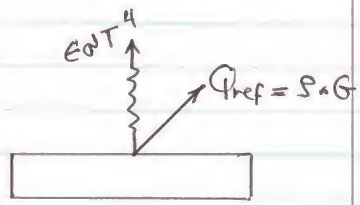


$$G = Q_{ref} + Q_{abs} + Q_{Trans}$$

↓ The total incident radiation

- **Radiosity (J):**

The radiation leaving surface per unit area per unit time.



$$J = \rho G + \epsilon \sigma T^4$$

where

$\rho \Rightarrow$ reflectivity factor $= \dfrac{Q_{ref}}{G}$ and

$\epsilon \Rightarrow$ Emissivity factor $\longrightarrow$ $\epsilon = \dfrac{Q_{real}}{Q_{b.b}}$

ⓑ **The black body:**

The black body is an ideal surface having the following properties: ① A black body absorbs all incident radiation, regardless of wave length and direction. ② For all temperatures and wave lengths no surface can emit more energy than a black body. ③ Although the radiation emitted by a black body is a function of wave length and temperature, it is independent of direction. That is, the black body is diffuse emitter. $E_b \propto (\lambda, T)$

$\Rightarrow$ For black body: $\epsilon_{b.b} = 1$ and $\alpha_{b.b} = 1$ also $R_{sur_{b.b}} = 0$

ⓒ $\epsilon_{th} = 0.9$, $T_{th} = 20°C$, $T_w = 5°C$ and $h = 8.3\ W/m^2 °C$

Req.: $T_{air} = ?$ equating $\dot{Q}_{conv} = \dot{Q}_{rad}$ $\Rightarrow$ per unit area

$$h(T_{air} - T_{th}) = \epsilon_{th} * \sigma (T_{th}^4 - T_w^4)$$

$$T_{air} = T_{th} + \frac{\epsilon_{th} \cdot \sigma (T_{th}^4 - T_w^4)}{h} = 20 + \frac{0.9 * 5.67 * 10^{-8} \cdot (293^4 - 278^4)}{8.3}$$

$$T_{air} = 20 + 8.59 = 28.59°C$$

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